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ON THE GEOLOGY OF THE ISLAND OF AQUIDNECK AND THE NEIGHBORING PARTS OF THE SHORES OF NARRAGANSET BAY.*

[Concluded from page 528.]

BY PROF. N. S. SHALER.

Glacial Deposits and Ice Marks.—The contour of a surface alone is generally sufficient to establish the former existence of glaciers, if they have ever worked upon it, but it is not to these indications alone that we must look for the evidence of the work of this great agent in this region. Every mass of rock exposed to view shows the rounded, smoothed and scored surface so characteristic of ice work. Every part of the island, level enough to carry such material, is buried beneath a coating of detrital material from two to forty feet in thickness. We propose to study these deposits of glaciated matter with a view to determine some of the more important features connected with the work done by moving ice.

These deposits have a composition which varies considerably according to the position in which they are found. At the extreme northern end of the island, all the pebbles found in them are from rocks which belong beyond its limits. The greater part of the pebbles can be referred to rocks which are in place on the shores of Mount Hope Bay to the northward, though some seem to come from points as far up as the neighborhood of Taunton. Only a small part cannot be readily referred to materials in place in the basins of the streams which flow into Narraganset Bay. It is of course impossible to assert that none of these unreferred specimens came from more remote regions to the northward, but inasmuch as there is a very wide difference noticeable between the glacial material in the basin of the Charles River and the other streams which flow into Massachusetts Bay, and this drift on the north of Aquidneck island, there can be little doubt that the transportation of erratics, from limits more than fifty miles away, has been very slight indeed, if it occurs at all. A large part of the drift mass is made up of boulders of a conglomerate, which reminds one of the pudding stone in the neighborhood of Boston, but it differs from that rock in the comparative abundance of the matrix, and scarcity of pebbles of large size. The pebbles are, moreover, composed of different sorts of rock from those in the Boston conglomerates. After a careful inspection, I am compelled to conclude that none of the conglomerate masses are from that set of beds, which extend over the country to the north and east of the Blue Hills near Boston.

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*This paper is taken from a report made to Prof. Benj. Pierce, Superintendent of the United States Coast Survey, and is published by his permission.

On the northern part of the island, a few of the syenite cliffs, which rise at steep angles from the plain, are the only points which have no drift matter upon them. Between these cliffs and the north slope of Butts Hill is a plain much indented by singular depressions already described (*vide supra* p. 523). The drift here has an unknown depth; it is known to be more than fifteen feet in thickness, and is probably at some points as much as forty feet thick. The pebbles here are with very rare exceptions less than six inches in diameter and are heaped together with only imperfect stratification. The cementing matter differs in no way from that which is always found in our boulder deposits, being a mixture of all the kinds of materials which go to make up the pebbly part of the deposit. There is no trace of true moraine heaps, such as fill the valleys in front of existing glaciers, in this part of the island. All the drift has, more or less, the character described by Agassiz, and by him referred to the melting of a great ice sheet, and the deposition, in a great unstratified mass, of all the pebbles which it had torn from its bed. Following the drift southwards, we find that without much change of volume the constituents become greatly altered in character. A large part of the materials which are found in it at the extreme northern end disappear, and are replaced by fragments from the rocks which belong in the immediate neighborhood. This is very clearly seen in the beds which overlie the portion of the island which contains coal. The matrix or cement of the mass is here much darker than in the drift near Blue Bill Cove; a large part of the fragments are of slate of a carbonaceous character. This blackish color extends to the drift found to the south of the coal field, though it becomes less and less marked as we go away from the source of supply of the coal. On the eastern shore we gradually leave the syenite boulders behind us as we go from north to south. Fragments of this sort of rock, which made up about one-half of the drift near

Anthony's, become rare when we get as far south as the glen, and are almost entirely wanting at Sachuest Neck. The conglomerate, with very much compressed pebbles, which does not occur north of the east and west line drawn from Black Point to Lawton's valley, is not found in the drift to the north of that line, though not infrequent in the beds of that age at all points to the southward of it. The north end of the island has a great quantity of conglomerate erratics but they belong to the type of that rock found to the north of Somerset on the Taunton River, and probably at other points in the direction whence came the glacial stream.

It will be shown further on that at various points the underlying rock of the island is traversed by veins of white quartz often having a thickness of many feet; the position of these veins, even when the rock in place is hidden, is often made evident by the trains of quartz blocks which lie mingled with the boulder mass, to the south of the outcrop of the vein. The actual thickness of the drift diminishes pretty steadily as we go southward; this is doubtless to be attributed to the soft character of the rock which underlies the island. That which the glacial stream rent from the bottom, in that part of its course which lies just north of the island, was of a much more resisting character than that which it encountered in its course over the island itself; naturally the endurance of the rock masses ground beneath the glacier was in proportion to the hardness of the material of which they were composed, so that where the rock was very soft the rapid disappearance of its fragments would prevent a great accumulation of débris.

Professor Agassiz has already called attention to the essential difference in the character of the débris of the wearing in the two modes in which glaciers may act. 1st, where the ice is in the form isolated streams bounded by distinct rock walls, as in the existing glaciers of Switzerland. 2d, where the ice is spread broadly over the surface of the continent, attaining to a depth which quite deprives it of all bounding walls, giving us a sea of glacial matter in place of the rivers of ice in the other condition. In the first condition of the ice, the rock boundaries of the streams furnish comparatively the larger part of the material transported by the glacier; something is torn away from the bed by the moving stream, but its comparatively thin mass gives it no such abrading power as is possessed by the far thicker continental glacier. This last named form of the action can only take up masses of material from the base over which it grinds; its ability to rend fragments from the rock beneath it would always be far greater than the stream glacier, on account of its superior thickness and therefore far greater crushing power.

Examination of the materials deposited by these two forms of ice action shows us enough difference between them to enable us to determine to which of the two any given mass of glacial material belongs. Where a large part of the fragments are angular, showing no trace of grinding against the bottom of the glacier, we may assume that the ice which carried the material was a local stream which received the mass of its load from that part of the sides of the valley in which it flowed which were above the level of the ice; where on the contrary the whole of the débris is more or less rounded, a large part polished or scored, and all showing the effect of the abrasion which must occur when the fragments are dragged from their bed by the moving ice, we must conclude that the sheet had no side barriers from which a supply of débris could be furnished by falls and avalanches, as the existing glaciers in Switzerland are fed, but obtained their whole load from the bed rock.

I am well convinced that all the débris on the island of Aquidneck has been deposited by ice acting in the last of these two methods. Possibly there may have been a little action of a more local character, but the evidence forces us to the conclusion that the principal part of the drift found here has been deposited by the melting of a mass of ice in which it was held, rather than by ice streams heaping it up in the form of moraines. The probability that this was the method by which the glacial detritus was transported renders it the more likely that all the material is of local origin. Rock masses resting on the surface of a glacier are in a position favorable for transportation to the greatest distance that the stream can flow; not so the detritus which rests between the mass of ice and the bed rock. All the material torn up from its bed by the glaciers must remain permanently near to the same relative level in the ice mass, close to its base, for there is no possible means whereby they could become lifted into the upper parts of ice. Here they would be exposed to the wearing action which results from continual grinding against the bed of the stream or constant friction against each other; this must lead to their speedy destruction. We thus see that by far the larger part of the eroded materials of the ancient continental glaciers must have been rapidly converted into mud which would have been easily swept away by the sub-glacial streams, which would have coursed beneath the great ice sheets of this region, just as they now flow beneath the Greenland glaciers and bear their tide of muddy water to the sea.

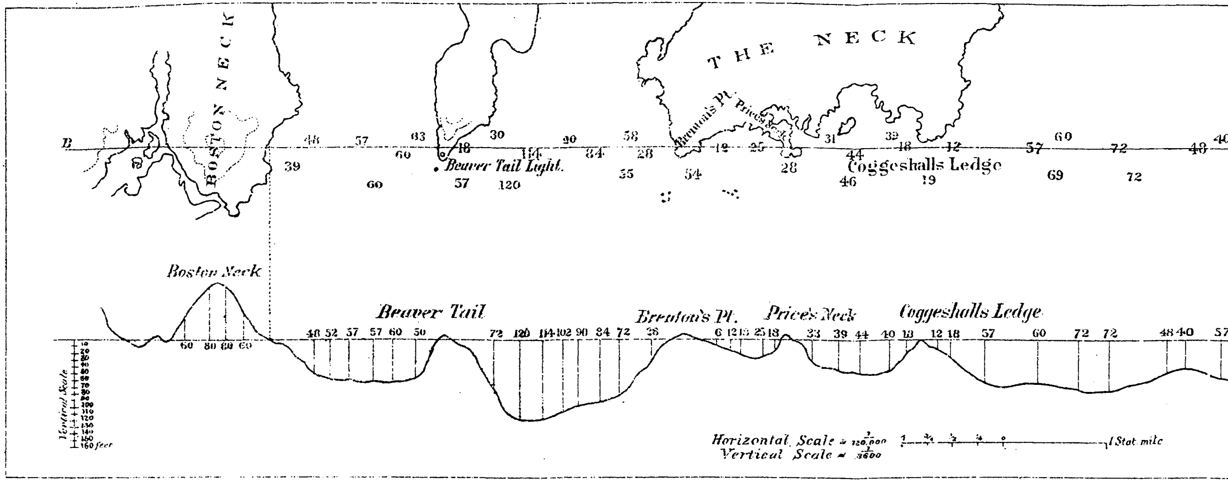
There are only two points where the glacial deposits seem capable of any other interpretation. Two-thirds of a mile north of the coal mines on the west side of the railway, there is a mass of drift having a form which strongly suggests that it might have been deposited as a terminal moraine. It is in the form of a ridge a few hundred feet long, and by its position, shape and structure is likely to have been the mass accumulated during the retreat of the ice stream when it paused for awhile with its termination at that point. The other point is at Portsmouth Grove, a few hundred feet to the south and east of the railroad station, where the drift is piled in a number of conical hills which lie in a general north and south direction. The internal structure is not shown by sections as at the other point, but there can be no reasonable doubt that the whole mass is of drift material. It is pretty clear that these hills have been formed in a different way from the rest of the drift; there seems no other reasonable explanation than to suppose that they were also formed by a retreating ice stream.

The evidence concerning the history of the glacial period, given by the remains it has left behind, is essentially the same as that which we find over the region to the northward. A period during which the ice sheet wrapped the land and extended far out to sea was succeeded by a time of rapid shrinking of the ice, rapid in a geological sense, though its complete passing away may have required several thousand years. During this period of retreat, the various channels of Narraganset Bay may have had more or less well defined glaciers, and these, though they would have gathered little débris upon their surface owing to the low nature of their bounding walls, would still heap up mounds at their terminations, at those points where their retreat may have been from time to time interrupted.

The actual amount of erosion during the last glacial period is not readily determined; there is some interesting evidence, however, to be gained from a study of certain instances of wear found on Aquidneck Island. Wherever there is a mass of rock which juts abruptly from the general surface, it shows some of the peculiar marks of southward moving ice; besides the universal smoothing and scoring of the surface, each of these projections shows us the phenomena of "shock and lee sides," and the northern end is always more worn than the southern end. All the precipitous slopes of any considerable area are upon the faces away from the northern side of the masses to which they belong. This sort of evidence is visible in most regions which have been subjected to glacial action, but at two points on this island it takes a shape which has not been observed at other points on our coast. In the felsite district south of Newport Harbor there are many admirable specimens of rounded bosses of rock, the "roches moutonée" of the French geologists. These, one and all, show on careful study more or less of the shock and lee sides. There is one of these felsite masses which has its northern end riven into massive fragments which have been pushed around towards the south in such a fashion as to make the direction of the force very evident. We see here the prodigious rending force of the glacier, for there has been separated at one moment a mass of rock sufficient to furnish at least one hundred tons of boulders to the ice current.

The mass of conglomerate and associated materials known as Paradise Rocks also shows some interesting phenomena. These rocks consist of a set of ridges of steeply inclined beds of varying hardness, which owe their position to a number of parallel faults extending in a north and south direction with a considerable *throw*, so that the projecting edges of the rocks rise at sharp angles to the height of from fifty to one hundred and fifty feet above the sea level. Carefully tracing these rocks in the direction in which they are continued to the northward, it becomes evident that, at the time when they were formed, the ridges continued for several hundred feet to the northward of the base of the slopes which lead down to the comparatively low land which now bounds them on that side. We cannot resist the conviction that the powerful agent which has cut away these solid masses of rock was the ice stream which has so clearly scored their surfaces and left the marks of its power on every square foot of their remaining surfaces.

Very little of the surface of the island remains in precisely the condition in which it was at the time of the coming of the white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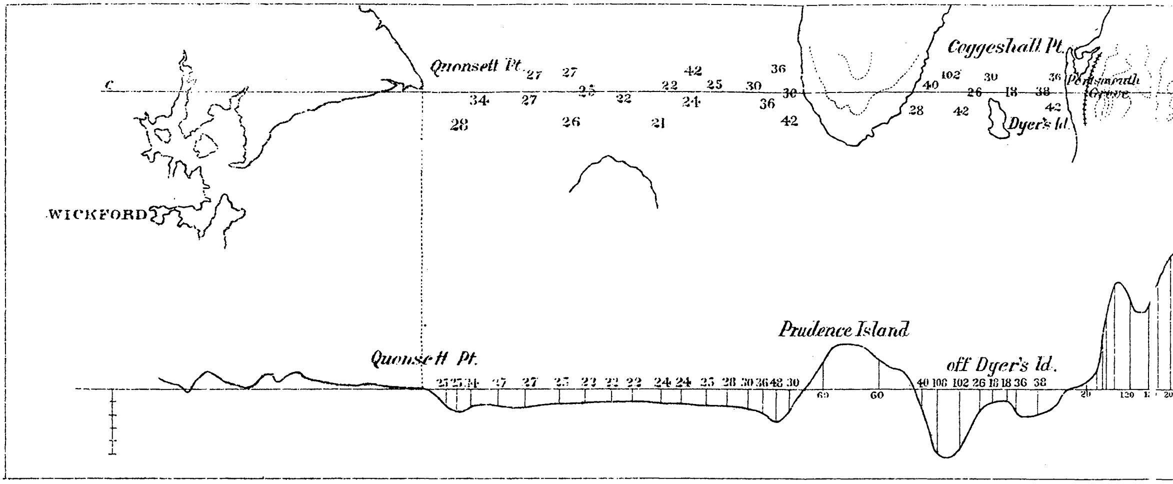
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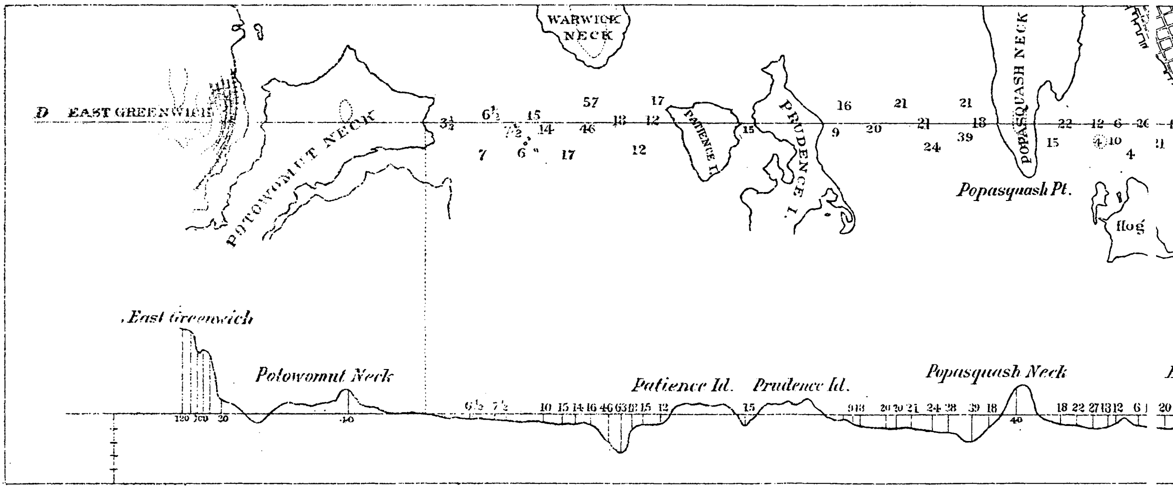
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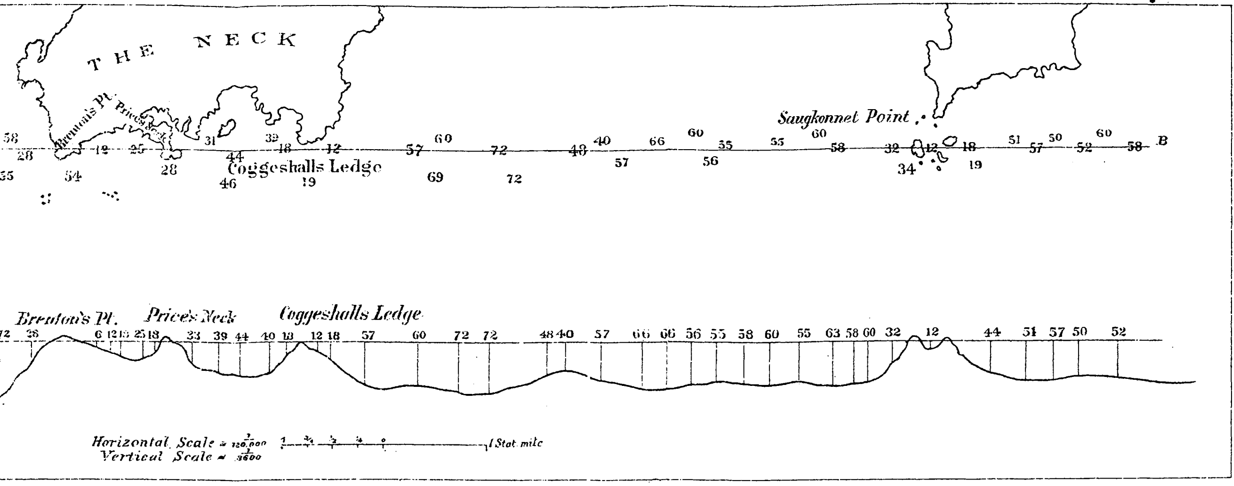

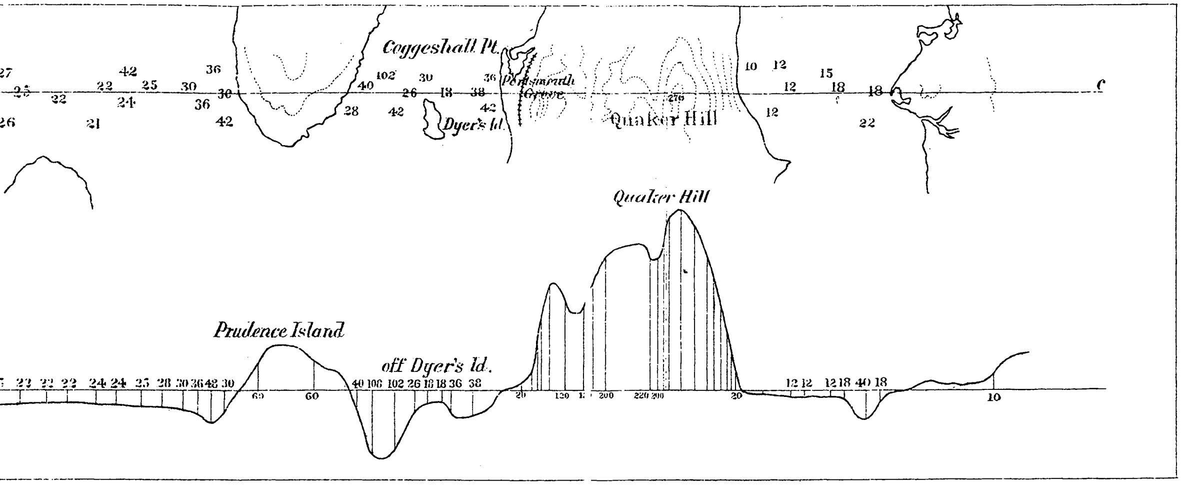

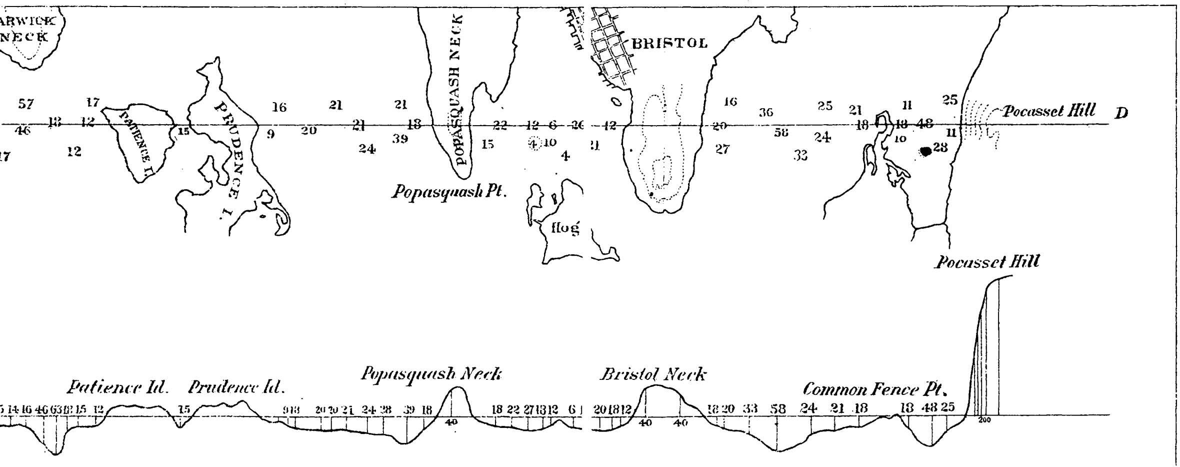

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men; there can be no doubt, however, that it was quite uniformly covered with boulders of varied size. The thousand miles or thereabouts of stone walls which are found upon the island attest the original abundance of these surface boulders. Most of the larger masses have been broken up in order to be used for building purposes, but there still exist several thousand erratics having a diameter of more than three feet which have been deported from the cultivated fields, or lie in the regions which are too barren for cultivation. If we examine the sections in the drift, visible at various points, and notice the comparative variety of large boulders, it seems no easy matter to account for these numerous surface erratics without resorting to some such agency as floating ice operating at the close of the principal glacial period. This method of explaining the abundance of surface erratics is much in favor with many European geologists. There are many arguments against it, however, which make it in the highest degree unlikely that it was the main agent. On the highest hills these boulders abound the most; now there is every reason to believe that there has been at the most not over forty feet of subsidence on this shore since the beginning of the glacial period; a depression so considerable as to have lowered the level of the highest hills of Aquidneck island beneath the level of the sea, must have left some recognizable evidence of its existence. There is, however, no evidence sufficient of such a change of level. We can more satisfactorily account for the facts by assuming that these boulders of large size owe their abundance to the following causes. The rock masses in the glacier which were furthest from the rock bed would receive the least attrition and therefore remain the largest in size; moreover, the continual wear to which the upper part of the drift bed has been subjected has served to wash away a large quantity of the mud, which forms a great part of the mass, leaving the pebbles of various sizes accumulated on the surface. These great boulders should, on account of their superior position, have been riven from their parent rock at a greater distance from their present position than the other which lies below them. It is a tolerably safe conclusion that the lowermost pebbles in the mass which were riven by the ice from the bed rock, would be the last additions to the accumulation. Each successive accumulation would lift the débris which was already in existence, so that while in the time immediately after its separation from its bed the fragment of rock would be subjected to great wear, it might, by the subposition of fragments more recently sundered, be gradually lifted out of the level of greatest attrition into a level where it would be carried without much wear. When the rock over which the ice flowed yielded fragments more rapidly than they were ground up, the conditions would be the most favorable for distant transportation; when, on the other hand, if the grinding of the pebbles went on more rapidly than they were supplied, the chance of distant transportation would be small. This is well illustrated over the southern part of Aquidneck island. When the glacier swept over the friable slates, the drift drawn from the northern end of the island kept in security in the upper part of the débris; when it passed on to the southern part of the section where the hard felsites and argillites were encountered, the packing of soft shale was quickly ground up, and then the syenite pebbles were let down upon the bed rock and soon reduced to fine material. The result is that the region known as the neck, south of Newport, has a very thin coating of drift matter.

All the boulders, of whatever size they may be and at all positions in the débris, show evidences of abrasion which cannot be explained without supposing that they were derived from the floor of the ice mass, and passed through the inevitable jostling which must occur while they were at the bottom of the pack.

There can be no question but that the retreat of the ice across the section given in this island must have been, in a geological sense, very rapid. The evidence is clear that at one time it extended far to the seaward of the southern end of the island, so far indeed, that we can find no distinct evidence at this point of the great masses of débris, which must have been deposited at the outer border in the shape of a great terminal moraine. As the ice went back, if its retreat had been by successive steps, any of which brought the edge of the ice across this island, the result would have been the formation of a distinct terminal moraine. It cannot be said that such a mark would have been obliterated by subsequent changes, for the scratches which cover the uppermost pebbles of the drift would surely have been worn away by any erosion which could have had great effect on the contour of the surface. We are therefore justified in supposing that the glacial sheet retreated rapidly and steadily, when it passed from the surface of this part of our shore. It does not seem as if the term retreat could be used with propriety for the simultaneous melting, which appears to have taken place in the whole section here. I am inclined to think that the ice stream, no longer fed with glacial matter and probably wasted by great rains and a strong heat, gradually came to rest, and then the same process of decay slowly separated the water from the stones, dropping them into their present resting places.

The evidence of a readvance of the glacial matter, not in the form of a great sheet, but in the shape of separate streams, is by no means so clear here as it is to the northward. If it came at all it only lasted for a short time, and produced no considerable effects.

I am inclined to think, however, that both the east and west channels gave passage to ice streams which returned to them long after the main sheet had disappeared. These local glaciers did not, however, reach farther south than the middle of the islands.

The scorings upon the surface of the rock tell the same thing in all parts of the island; the general course is from the north by west towards the south by east, but the individual differences are considerable. Many scratches depart widely from this range. In the rude jostle which took place at the point of contact of ice and rock, there would necessarily arise just such changes of direction as are indicated on the rock surfaces. There is also a certain accommodation of direction of slope to contour of surface before a stout boss of rock, where the flexible stream would turn a little for an easier escape.

The cutting of the scratches is not as deep as in more northern regions; there is nothing like the long deep drawn grooves of northern Vermont, or the region about the Great Lakes. This may be due as much to the prevailing weakness of the cutting tools, the pebbles, as to a difference in the energy of movement of their setting, the ice. On Price's neck, a singularly good specimen of glacial erosion, the scratches are quite distinct and the amount of surface which shows ice action unusually large. The point of greatest interest connected with this locality is found in the evidence it affords concerning the depression of this region since the time when these furrows were graven. If it had been for any considerable time beneath the sea it would have surely been changed from its present character. I believe that most, if not all of it, was beneath the sea at the time when the glacial sheet passed away, but the reëlevation was so quick that even these faintly traced lines were not worn away. Equally strong is the evidence they give concerning the nearness of the time when they were made. Although the rock is not the most enduring, having a considerable tendency to shatter, they stand almost as fresh as the carvings on Egyptian stones.

In attempting to measure the influence of the glacial action upon this region the first question which arises is whether we are to refer the whole of the erosion which is clearly to be attributed to this agent to the action of the ice time which immediately preceded the present geological period, or must look upon it as having been in part the work of more ancient glacial periods. Besides the general argument that there is a great improbability in the supposition that there has been but one glacial period in the earth's history, we have other reasons for believing that glacial action has been a constantly recurring element in the successive geological stages. The hypothesis of Mr Croll, which up to the present time is the most satisfactory theory that has been presented to account for the coming of the ice time, makes the change depend entirely upon the alteration in the eccentricity of the earth's orbit, and the change in the place in that orbit when the northern and southern hemispheres get their winter and summer exposures to the sun. Whether these hypotheses prove well founded or not there can be no doubt that the past geological record shows us evidences enough of glacial action. Every great conglomerate is in itself such evidence ; nothing but a glacial period is competent to produce or transport, into their present position, such masses of pebbles as make up the conglomerate which is found in the carboniferous rocks of this island. At almost every stage in the earth's history we have the same sort of accumulations. They abound in the primordial, are frequent in the palæozoic and mesozoic, and numerous in the tertiary. The Roxbury conglomerate found in the town of that name, and over a large part of the south and west shores of Massachusetts Bay, is so much like the modern drift, that at one point, where it is rather more incoherent than usual, the eye does not at first readily detect the difference between the glacial beds of the geological yesterday and the underlying conglomerate of the primordial time, so close is the physical connection of these beds which are separated by nearly the whole life-bearing section of the earth's crust.

The fact noticed in the paper on the Topography of Aquidneck Island (see Vol. vi, page 518), that the streams on this island have the arrangement natural to a local water system, shows that the channels which separate it from the main land had been excavated before the last glacial period. Now, as we have already seen, these channels have a shape which can only be accounted for by supposing that they were formed by the excavating power of ice. Therefore we are compelled to suppose that there was an ice action anterior to the glacial period which gave way to make our present time. If this be true of this section of our fiord zone, it is likely to be true for a large part of the topography of our shores which is dependent for its shape upon ice action. It would be imprudent to rest so large a determination upon such a small basis of observation; the question is, however, one which invites the consideration of all those who are interested in working out the history of our continent. Nor is the problem one of local interest alone; our whole conception of the conditions under which life has been developed and the successive sheets of strata laid down will be greatly modified by such a view of the past as would be forced upon us when we recognized glaciation as a constant factor in the evolution of the physical and vital history of our earth. We need some conceivable agent whereby the life of the past could have been subjected to ever varying conditions. If it has been driven in endless chase from equator to poles by the alternating changes of heat and cold, these variations would have succeeded each other with startling rapidity. This view is consonant with all we know of life in the past; it furthermore seems in the highest degree fitting that life, the product, the localization of solar energy, should find the spur that drove it onwards and upwards in the changes of its motive force.